VACUUM JACKETING VS. STEAM JACKETING

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ARMOUR INSTITUTE OF TECHNOLOGY

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Vacuum jacketing vs. steam
jacketing

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VACUUM JACKETING
vs
STEAM JACKETING

A THESIS

PRESENTED BY

TANDY E. GENTRY
and
FRANK E. WERNICK

TO THE

PRESIDENT AND FACULTY

OF

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HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING G

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VACUUM JACKETING

- vs. -

STEAM JACKETING.

Since the thermos bottle is such a successful preventative of the transfer of heat, as for instance in the preservation of liquid air at atmospheric pressure, it has been thought advisable to test the effect of vacuum jacketing on the cylinders of a steam engine.

The idea of this set of tests was conceived with the view of determining the relative steam consumption of an engine using vacuum as a jacketing medium as compared with that when using steam.

The engine upon which these tests were conducted is a horizontal cross-compound testing engine built for the Mechanical laboratory of the Armour Institute of Technology, by the Allis-Chalmers Company, of Milwaukee. It is

22139

rated at seventy-five horse power when running at ninety revolution per minute and under an initial pressure of one hundred and fifty pounds per square inch. Both high and low pressure cylinders have provisions made for jacketing heads and barrel. The diameters of the high and low pressure cylinders are respectively nine and eighteen inches, with a two foot stroke. The governor is of the fly-ball type.

The engine exhausts into a Wheeler surface condenser having three hundred and sixty four tube five-eights of an inch in diameter and seven feet one and three quarters inches long, giving a condensing surface of four hundred and thirty two square feet. The cooling water used flowed through the condenser by city main pressure, the water piston of the pump having been removed.

The low pressure side of the engine was dismantled, by removing the piston, connecting rod, and eccentric rods and only the high

CONSTANTS.

Engine Cylinder:

Head End Clearance	- -	11.1 %
Crank End ,,	- -	11.4 %
Diameter of Cylinder	-	9.0 "
Length of Stroke	- -	24.0 "
Diam. of Piston Rod	-	1.875 "

Wheeler Surface Condenser:

Condensing Surface	-	457 sq. ft.
Number of Tubes	- - -	364
Diam. of Tubes	- - -	.625 "
Length of Tubes	-	7 ft. 1.75 in.

Condenser Pump:

Stroke	- - - - - -	10.0 "
Diam. Air Cylinder	- -	9.0 "
,, Steam Cylinder	-	8.0 "
,, Water Cylinder	-	9.0 "

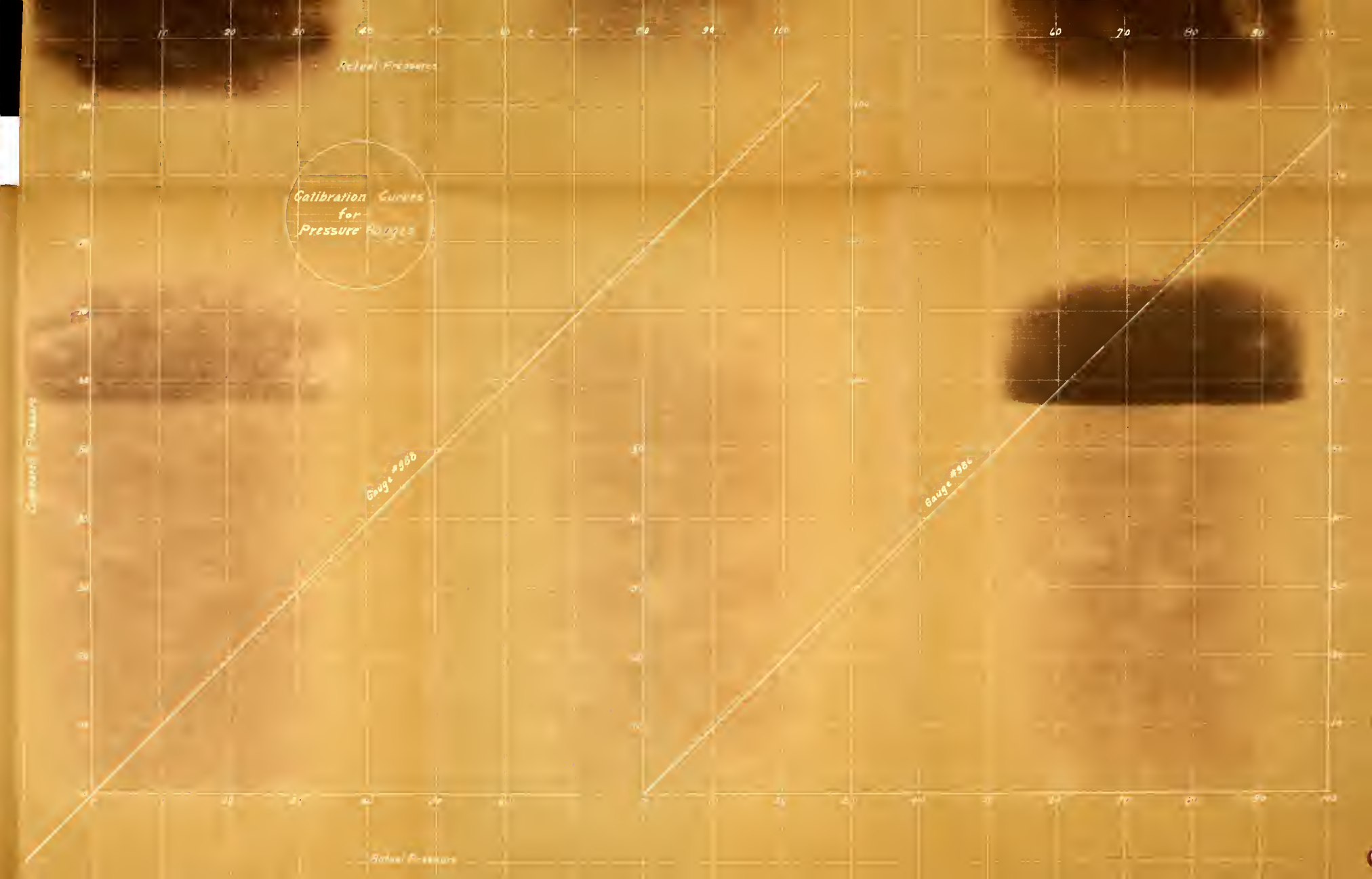
Prony Brake:

Length of Arm	- - -	47.625 "
Tare Weight	- - - -	47.5 #

pressure cylinder used in these tests.

The prony brake, which has been fitted to the main shaft since the engine was erected, was used to absorb the power developed. A split pulley was used and the leakage of cooling water through the joints gave a continually changing coefficient of friction between the pulley and the strap.

The jackets of this engine had never been used before. It was necessary, therefore, in preparing for the tests to connect them by suitable piping, with sources of both steam and vacuum. Openings in the upper portions of both heads and barrel were connected by three-quarter inch pipe with an Edwards air pump. A branch was put in connecting with the steam pipe supplying the cylinder. Valves were placed in both the branch and main line to facilitate shifting from vacuum to steam jacketing. The drains from the lower portions of the heads and barrel were connected in a similar manner with a trap to take care of condensation when


Calibration Curves
for
Pressure Gauges
Gauge #986
Gauge #986
Actual Pressure
Actual Pressure
Gauge Pressure

steam jacketing was used.

Calibration of Instruments.

The steam pressure gauges were calibrated from zero to one hundred by five pound increments on a Crosby gauge tester. The curves for the necessary corrections are included as a part of this report.

The standards used in the calibration of our thermometers were obtained from the Physics Department. That used in the calibration of the cooling water and condensed steam thermometers was a (0 - 100) Centigrade, and that used in the calibration of the calorimeter thermometer was a (0 - 150) Centigrade. The former were compared with the standard in a water bath up to 120 degrees Fahrenheit and the latter in an oil bath up to 280 degrees Fahrenheit.

The indicator springs were calibrated in a testing line having valves in the supply and exhaust so that the pressure could be varied

at will. Readings were taken at interval of ten pounds with both increasing and decreasing pressure. The average of these readings corresponded so closely with the scale of the spring that it was thought advisable to call them correct. On the following page will be found the results of an average set of readings.

The scales used were tested with standard test weights and found to be correct.

A calibration test of two hours duration was run on the Worthington water meter in the cooling water line, varying the flow from three and a half to seven cubic feet per minute. A curve was drawn for the same plotting cubic feet per hour against pounds per hour. It was found, in trying to check calculations by the weight of cooling water as indicated by the meter readings, that these results were not reliable, owing to fluctuation in water pressure.

Sample Calibration of Indicator Spring.

[illegible]	Measurements from Cards in Inches			Indicated Pressure	Error
In Ins.	Up	Down	Mean		
10	.40	.15	.175	10	0.0
20	.32	.30	.245	[illegible]	− .4
30	.74	[illegible]	[illegible]	[illegible]	− .4
40	.47	.54	.505	[illegible]	.4
50	.60	.46	.63	[illegible]	.4
60	.71	[illegible]	.74	[illegible]	− .2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.[illegible]	1.[illegible]	1.[illegible]	[illegible]	[illegible]

General Plan.

The plan for the preliminary work of this set of tests was to make three consecutive runs of two hours duration each on the engine for each method of jacketing used. The first three were to be made without jacketing of any kind in order that it might be seen whether either method gave any appreciable gain in steam consumption. The second three were to be made with vacuum jacketing; the degree of vacuum used to be the best obtainable with the Edwards air pump. And the third set of runs were to be made with steam jacketing; the pressure and quality of the steam supplied to the jackets being the same as at the throttle. All runs were to be made with a constant gauge pressure of eighty pounds at the throttle and with a gross load of five hundred pounds on the scales. Additional runs were then to be made as the results of these might indicate was desirable.

Method of Procedure.

The steam pressure in the main varied to such an extent that constant adjustment of the throttling valve in the supply pipe was required to maintain the desired eighty pounds at the throttle. At times the pressure dropped so low that it was necessary to shorten the length of the run.

The back pressure was measured by means of a manometer attached to the exhaust pipe at the engine so as to avoid errors due to any drop in pressure in the piping between engine and condenser. The best degree of vacuum that the Wheeler condenser would give was about twenty five inches of mercury. The failure to get a better vacuum was partly due to a defective valve in the air pump.

The quality of the steam at admission was determined by a throttling calorimeter in the supply line just above the cylinder.

Each end of the cylinder was provided

with a Crosby indicator so that cards might be taken simultaneously.

A continuous counter was attached to the valve gear of the engine which registered the number of revolutions. Its reading was taken at intervals of thirty minutes, both as a check upon the uniform speed of the engine and as a precaution against possible accidents spoiling the data for the entire run.

The temperature of the condensed steam was kept well below a hundred degrees Fahrenheit in order to prevent errors due to loss by vaporization after leaving the condenser. It was pumped from the condenser to weighing tanks and the weight taken every thirty minutes.

A low pressure trap was used to take care of condensation in the jackets when steam jacketing was used. It would not discharge under the pressure used. In order to discharge the trap it was necessary to close the valve in the line to the jacket and releive the pres-

sure by opening the vent cock. This made it possible to drain the condensation at the beginning and end of each run. The trap water was weighed and added to the condensed steam in calculating the steam consumption for the steam jacketed runs.

The flow of cooling water through the condenser was made sufficient in each case to give a temperature well below one hundred degrees Fahrenheit, to the issuing condensed steam. The average rise in temperature of the cooling water being from about forty six to ninety degrees. When using the Edwards air pump on the vacuum jacket, it was necessary to use water from the same line in order to condense enough steam to seal the valves. This source of error, together with the unreliability of results obtained from meter readings made it impossible, under the existing circumstances, to do anything but estimate the quantity of cooling water supplied to the condenser.

Cards were taken at ten minute intervals during each run, as were also readings of calorimeter, in and out going cooling water, and condensed steam temperatures, back and condenser pressures.

Run No. 1

No Jacketing — April 15th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
10:15	0474	80	23.50	246	2.10	3.84	43.7	1.85	3.66	40.4
10:25		"	23.50	246	2.07	3.83	43.2	2.07	3.88	42.7
10:35		"	23.60	247	1.94	3.82	40.7	1.93	3.86	40.0
10:45	3415	"	23.80	246	2.13	3.82	44.[illegible]	2.12	3.85	44.0
10:55		"	23.80	246	2.02	3.82	42.3	2.02	3.86	41.8
11:05		"	23.80	244	2.12	3.82	44.4	2.05	3.86	42.5
11:15	6295	"	23.60	246	2.06	3.82	43.1	2.03	3.85	42.2
11:25		"	23.70	248	2.10	3.81	44.0	2.04	3.83	42.6
11:35		"	23.80	245	2.12	3.81	44.5	2.03	3.70	43.9
11:45	9165	"	23.80	244	2.08	3.84	43.3	2.02	3.84	42.0
11:55		"	23.70	243	2.08	3.81	43.7	2.02	3.86	41.8
12:05		"	23.80	245	2.05	3.82	42.9	1.87	3.70	40.4
12:15	12045	"	23.80	244	2.15	3.82	45.0	2.00	3.72	43.0
Ave.		80	23.70	245.4			43.5			42.1

Barometer 29.12" Hg.

Condensed Steam		2258.5#
Total Steam		
Average R.P.M.		96.4
Average M.E.P. (H.E.)	43.5 (C.E.)	42.1
Indicated Horse Power		31.1
Brake Horse Power		28.8
Mechanical Efficiency		92.6%
Steam per I.H.P. per hr. (Dry)		35.5#

R. E. Gruetzy

H. E. Wernick

Run No. 2.

No Jacketing — April 21st 1910.

Time	Rev Counter	Steam Pres.	Back Pres.	Cal Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
10:43	6356	80	24.40	249	2.16	3.82	45.2	2.04	3.87	42.2
10:53		80	24.60	245	2.17	3.83	45.[illegible]	2.07	3.88	42.7
11:03		76	24.70	244	2.13	3.81	44.7	2.00	3.87	41.3
11:13	9226	70	24.70	242	2.16	3.82	45.2	2.02	3.87	41.7
11:23		70	24.80	239	2.08	3.83	43.5	2.02	3.87	41.7
11:33		76	24.00	241	2.06	3.83	43.0	2.00	3.87	41.3
11:43	11096	76	24.70	243	2.12	3.84	44.2	2.06	3.86	[illegible]
Ave.		75.4	24.56	240.4			44.44			41.94

Barometer 29.34" Hg.

Condensed Steam		1221.5#
Total Steam		
Average R.P.M.		95.6
Average M.E.P.	(H.E) 44.44	(C.E) 41.94
Indicated Horse Power		31.15
Brake Horse Power		28.60
Mechanical Efficiency		91.8
Steam per I.H.P. per hr. (Dry)		39.6#

F. E. Gentry

F. E. Wernecke

Run No. 3.

No Jacketing — April 25th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
10:30	5170	78	24.5	251	2.07	3.86	42.9	2.05	3.87	42.3
10:40		80	24.6	242	2.02	3.85	42.0	2.02	3.87	41.7
10:50		78	24.5	244	2.17	3.87	44.8	2.13	3.89	43.8
11:00	8050	77	24.6	240	2.11	3.86	42.7	2.03	3.88	41.8
11:10		80	24.6	241	2.09	3.85	43.4	2.02	3.89	41.5
11:20		78	24.6	242	2.11	3.86	43.7	2.14	3.88	44.1
11:30	10930	80	24.6	244	2.15	3.87	44.5	2.08	3.89	42.8
11:40		79	24.7	242	2.14	3.87	44.2	2.11	3.88	43.5
11:50		76	24.7	239	2.16	3.86	44.8	2.05	3.85	42.6
12:00	13805	80	24.6	238	2.30	3.86	47.6	2.14	3.88	44.1
12:10		80	24.6	246	2.17	3.86	45.0	2.16	3.88	44.5
12:20		80	24.8	242	2.15	3.86	44.5	2.13	3.89	43.8
12:30	16690	80	24.7	242	2.14	3.86	44.3	2.10	3.89	43.2
Ave.		79.0	24.6	242.5			44.26			43.06

Barometer 29.33" Hg.

Condensed Steam			2264.0#
Total Steam			
Average R.P.M.			95.8
Average M.E.P.	(H.E.) 44.26	(C.E.)	43.06
Indicated Horse Power			31.62
Brake Horse Power			28.65
Mechanical Efficiency			90.6%
Steam per I.H.P. per hr. (Dry)			31.50#

F. E. Keeley

F. E. Wernicke

Run No. 4.

Vacuum Jacketing. April 25th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
12:50	8595	80	24.4	238	2.17	3.86	45.0	2.15	3.89	44.2
1:00		80	24.6	244	2.09	3.87	43.2	2.07	3.89	42.6
1:10		80	24.5	242	2.19	3.86	45.4	2.08	3.88	42.8
1:20	11485	80	24.5	242	2.16	3.85	44.9	2.08	3.88	42.8
1:30		80	24.5	243	2.10	3.87	43.4	2.02	3.89	41.5
1:40		80	24.5	242	2.15	3.87	44.5	2.04	3.88	42.0
1:50	14345	80	24.5	244	2.11	3.87	43.6	2.02	3.88	41.6
Ave.		80	24.50	242			44.3			42.5

Barometer 29.33" Hg.

Degree of Vacuum in Jacket				26.0"
Total Steam				1125.0#
Average R.P.M.				96.0
Average M.E.P.	(H.E.)	44.3	(C.E.)	42.5
Indicated Horse Power				31.34
Brake Horse Power				28.70
Mechanical Efficiency				91.6%
Steam per I.H.P. per hr. (Dry)				35.23#

F. E. Gentry

H. E. Wernicke

Run No. 5

Vacuum Jackets — April 27th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
10:10	0130	80	25.0	244	2.07	3.86	42.9	1.96	3.89	40.3
10:20		"	25.2	244	2.25	3.85	46.7	2.13	3.89	43.8
10:30		"	25.2	240	2.14	3.85	44.4	2.07	3.89	42.8
10:40	3008	"	25.2	241	2.14	3.87	44.2	2.03	3.89	41.7
10:50		"	25.2	240	2.15	3.85	44.7	2.05	3.91	41.9
11:00		"	25.2	244	2.03	3.87	42.0	1.99	3.91	40.5
11:10	5885	"	25.2	242	2.16	3.85	44.8	1.97	3.89	40.6
11:20		"	25.3	244	2.23	3.84	46.5	2.07	3.90	42.4
11:30		"	25.2	240	2.19	3.85	45.5	2.05	3.89	42.1
11:40	8770	"	25.2	240	2.08	3.85	43.2	1.95	3.89	40.1
11:50		"	25.3	242	2.18	3.86	45.2	2.02	3.89	41.5
12:00		"	25.2	240	2.20	3.87	45.5	2.02	3.88	41.6
12:10	11645	"	25.2	242	2.16	3.86	44.7	1.94	3.88	40.0
Ave.		80	25.2	242			44.64			41.48

Barometer 29.6" Hg.

Degree of Vacuum in Jackets				25.3"
Condensed Steam				2164.0#
Average R.P.M.				96.0
Average M.E.P.	(H.E.)	44.64	(C.E.)	41.48
Indicated Horse Power				31.45
Brake Horse Power				28.70
Mechanical Efficiency				91.2 %
Steam per I.H.P. per hr. (Dry)				33.75#

F. E. Keeney

H. E. Wemick

Run No. 6.

Vacuum Jacketing — April 29th 1910.

Time	Rev. Counter	Steam Pres	Back Pres.	Cal. Temp.	H.E. Cards Area	H.E. Cards Length	H.E. Cards M.E.P.	C.E. Cards Area	C.E. Cards Length	C.E. Cards M.E.P.
12:20	2792	80	25.0	242	2.24	3.86	46.4	2.00	3.91	40.9
12:30		"	25.3	236	2.21	3.8[illegible]	45.8	2.16	3.98	44.5
12:40		"	25.[illegible]	241	2.16	3.86	44.7	1.98	3.89	40.7
12:50	5655	"	25.3	240	2.19	3.86	45.4	1.95	3.89	40.1
1:00		"	25.3	240	2.25	3.85	46.7	2.07	3.89	42.6
1:10		"	25.4	238	2.15	3.85	44.6	1.96	3.88	40.4
1:20	8560	"	25.4	239	2.09	3.86	43.3	1.96	3.89	40.3
1:30		"	25.4	238	2.25	3.85	46.7	2.07	3.88	42.7
1:40		"	25.4	239	1.91	3.86	39.7	1.84	3.89	37.9
1:50	11410	"	25.4	240	2.10	3.85	43.6	1.91	3.88	39.4
		80	25.32	239.3			44.69			40.95

Barometer 29.6" Hg.

Degree of Vacuum in Jackets				24.2"
Condensed Steam				1601.0#
Average R.P.M.				95.6
Average M.E.P.	(H.E.)	44.69	(C.E.)	40.95
Indicated Horse Power				30.78
Brake Horse Power				28.60
Mechanical Efficiency				92.9%
Steam per I.H.P. per hr. (Prs)				33.90#

P. E. Gretting
F. E. Wernick

Run No. 7.

Steam Jacketing — April 29th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards Area	H.E. Cards Length	H.E. Cards M.E.P.	C.E. Cards Area	C.E. Cards Length	C.E. Cards M.E.P.
9:10	4475	80	24.2	236	2.05	3.81	43.0	2.30	3.87	42.0
9:20		"	24.5	238	2.15	3.81	45.2	2.06	3.86	42.7
9:30		"	24.0	245	2.06	3.83	43.0	2.03	3.85	42.2
9:40	7370	"	24.6	242	2.14	3.82	44.8	2.08	3.85	43.2
9:50		"	24.6	240	2.16	3.83	45.1	2.13	3.87	44.1
10:00		"	24.6	238	2.19	3.81	46.0	2.12	3.85	44.0
10:10	10245	"	24.5	238	2.06	3.83	43.0	2.02	3.85	42.0
10:20		"	24.3	236	2.23	3.82	46.7	2.16	3.86	44.7
10:30		"	24.4	236	2.10	3.82	44.0	1.94	3.86	40.2
10:40	13140	"	24.6	238	2.12	3.82	43.4	2.00	3.87	41.3
10:50		"	24.7	238	1.95	3.81	40.9	1.90	3.88	39.2
11:00		"	24.7	240	2.31	3.82	48.5	2.14	3.88	44.1
11:10	16035	"	24.5	238	2.05	3.81	43.0	1.97	3.88	41.6
Ave.		80	24.52	238.5			44.2			42.33

Barometer 28.97" Hg.

Jacket Steam	26.42#	Cond. Steam		2136.0#
Total Steam				2162.42#
Average R.P.M.				96.3
Average M.E.P.	(H.E.)	44.2	(C.E.)	42.33
Indicated Horse Power				31.40
Brake Horse Power				28.80
Mechanical Efficiency				91.7%
Steam per I.H.P. per hr. (Dry)				33.65#

T. E. Gruting

F. L. Wemick

Run No. 8.

Steam Jacketing — April 29th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cul. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
11:10	6035	80	24.5	238	2.20	3.81	42.4	1.98	3.86	41.0
11:20		"	24.3	237	2.15	3.80	45.3	2.05	3.85	42.6
11:30		"	24.0	234	1.97	3.83	41.2	1.95	3.88	40.2
11:40	8910	"	23.8	234	2.01	3.84	41.8	2.02	3.87	41.8
11:50		"	24.3	239	2.03	3.82	42.5	2.03	3.87	42.0
12:00		"	24.5	238	2.00	3.82	41.8	2.10	3.88	43.3
12:10	11810	"	24.7	234	1.93	3.85	40.1	1.92	3.87	39.7
12:20		"	24.7	238	2.04	3.84	42.5	1.95	3.86	40.4
12:30		"	24.4	236	2.00	3.81	42.0	1.96	3.86	40.6
12:40	14690	"	24.2	238	1.95	3.82	40.8	1.91	3.87	39.5
12:50		"	24.0	232	2.10	3.80	44.2	2.06	3.88	42.5
1:00		"	23.8	230	2.00	3.80	42.1	1.93	3.86	40.0
1:10	17565	"	24.7	234	2.14	3.80	45.0	2.07	3.86	42.9
Ave.		80	24.30	236.3			42.44			41.27

Barometer 28.97" Hg.

Jacket Steam	47.88#	Cond. Steam	1983.0#
Total Steam			2030.88#
Average R.P.M.			96.1
Average M.E.P.	(H.E.) 42.44	(C.E.)	41.27
Indicated Horse Power			30.35
Brake Horse Power			28.75
Mechanical Efficiency			94.6%
Steam per I.H.P. per hr. (Dry)			32.7#

A. E. Guthy
H. E. Wenrich

Run No. 9.

Steam Jacketing — April 29th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
1:10	7565	80	24.7	234	2.11	3.81	44.3	2.00	3.87	41.3
1:20		"	24.7	236	2.13	3.80	44.8	2.06	3.87	42.6
1:30		"	24.6	238	2.10	3.80	44.2	2.06	3.87	42.6
1:40	10455	"	24.7	236	1.98	3.80	41.7	1.96	3.88	40.4
1:50		"	24.6	237	2.03	3.80	42.7	1.95	3.87	40.3
2:00		"	24.5	236	2.01	3.80	42.3	1.93	3.87	39.9
2:10	13340	"	24.7	237	1.96	3.78	41.5	1.95	3.86	40.4
2:20		"	24.7	238	1.94	3.79	40.9	1.91	3.85	39.7
2:30		"	24.5	241	1.95	3.79	41.1	1.92	3.86	39.8
2:40	16245	"	24.6	236	2.14	3.78	45.3	2.12	3.86	44.0
2:50		"	24.7	236	2.04	3.80	42.9	2.01	3.85	41.8
3:00		"	24.6	237	2.11	3.80	44.4	1.93	3.85	40.1
3:10	19125	"	24.5	235	2.01	3.82	42.1	1.98	3.85	41.2
Ave.		80	24.6	236			42.94			41.1

Barometer 28.97" Hg.

Jacket Steam	47.32#	Cond. Steam	1909.5#
Total Steam			1956.82#
Average R.P.M.			96.3
Average M.E.P.	(H.E.) 42.94	(C.E.)	41.1
Indicated Horse Power			30.54
Brake Horse Power			28.80
Mechanical Efficiency			94.27
Steam per I.H.P. per hr. (Dry)			31.30#

P. E. Gurley

H. E. Yunick

Run No. 10.

Steam Jacketing — May 4th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards Area	H.E. Cards Length	H.E. Cards M.E.P.	C.E. Cards Area	C.E. Cards Length	C.E. Cards M.E.P.
3:10	5230	80	25.5	237	2.07	3.86	43.0	2.09	3.92	42.6
3:20		"	25.5	237	1.98	3.85	41.2	2.02	3.90	41.5
3:30		"	25.0	237	2.17	3.85	45.1	2.11	3.90	43.3
3:40	8120	"	25.5	239	2.23	3.85	46.4	2.20	3.90	45.1
3:50		"	25.5	239	2.14	3.85	44.5	2.10	3.90	43.0
4:00		"	24.5	237	2.07	3.86	43.0	2.06	3.90	42.3
4:10	11020	"	25.5	239	2.19	3.85	45.5	2.18	3.90	44.8
4:20		"	25.3	239	2.17	3.84	45.1	2.12	3.90	43.5
4:30		"	25.4	235	2.17	3.85	45.1	2.13	3.90	43.7
4:40	13890	"	25.4	241	2.18	3.84	45.3	2.14	3.89	43.9
4:50		"	25.5	237	2.18	3.86	45.2	2.11	3.89	43.3
5:00		"	25.2	239	2.26	3.85	47.0	2.20	3.90	45.1
5:10	16770	"	25.8	237	2.14	3.85	44.5	2.07	3.90	42.5
Ave.		80	25.4	238			44.7			43.42

Barometer 29.93" Hg.

Jacket Steam	57.49# Cond Steam		1902.0#
Total Steam			1959.49#
Average R.P.M.			96.1
Average M.E.P.	(H.E.) 44.7	(C.E.)	43.42
Indicated Horse Power			31.92
Brake Horse Power			28.75
Mechanical Efficiency			90.1%
Steam per I.H.P. per hr. (Dry)			30.0#

F. E. Gretry

F. E. Wernick

Run No. 11.

Steam Jacketing — May 4th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
5:10	6770	80	25.5	230	2.16	3.85	46.0	2.13	3.90	43.7
5:20		"	25.5	252	1.94	3.84	40.4	1.93	3.90	39.6
5:30		"	25.3	248	2.15	3.85	45.8	2.12	3.90	43.5
5:40	9660	"	25.2	244	2.18	3.87	45.1	2.14	3.90	43.9
5:50		"	25.4	246	2.18	3.86	45.2	2.15	3.90	44.1
6:00		"	25.4	242	2.21	3.85	47.1	2.12	3.90	43.5
6:10	12510	"	25.4	242	2.10	3.85	44.7	2.04	3.90	41.9
Ave.		80	25.4	243.4			44.9			44.3

Barometer 29.93" Hg.

Jacket Steam	29#	Cond Steam	919.0#
Total Steam			948.0#
Average R.P.M.			95.8
Average M.E.P.	(H.E.) 44.9		(C.E.) 44.3
Indicated Horse Power			32.18
Brake Horse Power			28.65
Mechanical Efficiency			89.1 %
Steam per I.H.P per hr. (Ors)			28.9#

F. E. Guitry

H. E. Leonard

Run No. 12.

Steam Jacketing — May 4th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
6:20	3235	80	25.6	244	2.03	3.85	42.2	2.00	3.90	41.1
6:30		"	25.5	244	2.07	3.84	43.1	1.99	3.90	40.8
6:40		"	25.5	244	2.11	3.86	43.7	2.05	3.90	42.1
6:50	6110	"	25.4	246	2.18	3.85	45.3	2.10	3.90	43.1
7:00		"	25.4	244	2.04	3.86	44.8	2.11	3.90	43.3
7:10		"	25.3	241	2.14	3.87	42.2	2.01	3.89	41.3
7:20	9005	"	25.2	244	2.05	3.85	44.5	2.01	3.89	41.3
7:30		"	25.4	239	2.22	3.84	42.7	2.01	3.89	41.3
7:40		"	25.2	242	2.10	3.85	46.1	2.14	3.90	43.9
7:50	11870	"	25.2	244	2.14	3.85	44.7	2.06	3.90	42.3
8:00		"	25.0	242	2.05	3.85	42.4	2.01	3.88	41.4
8:10		"	25.1	249	2.04	3.85	42.6	2.01	3.90	41.3
8:20	14770	"	25.2	242	2.05	3.85	42.5	2.02	3.89	41.5
Ave		80	25.3	243.5			43.6			41.75

Barometer 29.93" Hg.

Jacket Steam	57.87#	Cond Steam	1901.0#
Total Steam			1958.87#
Average R.P.M.			96.1
Average M.E.P.	(H.E.) 43.6		(C.E.) 41.75
Indicated Horse Power			30.98
Brake Horse Power			27.75
Mechanical Efficiency			92.7 %
Steam per I.H.P. per hr. (Dry)			30.95#

P. E. Gentry

F. E. Wenrich

Run No. 13.

Vacuum Jacketing — May 5th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
11:50	0010	80	25.2	242	2.04	3.81	42.9	1.93	3.84	40.2
12:00		"	25.1	250	2.38	3.83	49.7	2.21	3.79	46.6
12:10		"	25.2	252	2.17	3.83	45.3	2.02	3.77	42.8
12:20	2883	"	25.2	249	2.24	3.85	46.5	2.12	3.76	40.1
12:30		"	25.2	250	2.11	3.85	43.8	1.95	3.75	41.6
12:40		"	25.4	252	2.01	3.85	41.7	1.82	3.70	39.2
12:50	5756	"	25.3	252	2.03	3.84	47.9	2.16	3.82	45.2
1:00		"	25.2	249	2.21	3.84	46.0	2.15	3.85	44.6
1:10		"	25.0	250	2.22	3.84	46.2	2.14	3.85	44.4
1:20	9625	"	25.3	249	2.03	3.85	42.2	2.04	3.85	42.4
1:30		"	25.1	248	2.16	3.84	45.0	2.09	3.85	43.4
1:40		"	25.0	250	2.16	3.84	42.9	2.03	3.85	42.2
1:50	11500	"	25.2	252	2.18	3.84	45.4	2.09	3.87	43.4
Ave		80	25.2	249.5			45.04			43.1

Barometer 29.86" Hg.

Degree of Vacuum in Jacket		26.25"
Condensed Steam		2152.5#
Average R.P.M.		95.75
Average M.E.P.	(H.E.) 45.04	(C.E.) 43.1
Indicated Horse Power		31.81
Brake Horse Power		28.6
Mechanical Efficiency		90.0 %
Steam per I.H.P. per hr. (Dry)		33.25#

P. C. Gretry

H. E. Wormack

Run No. 14.

Vacuum Jacketing — May 5th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
1:50	1500	80	25.2	252	2.00	3.85	41.5	1.99	3.88	41.0
2:00		"	25.4	254	2.24	3.84	46.5	2.15	3.88	44.3
2:10		"	25.4	254	2.21	3.85	45.9	2.14	3.87	44.1
2:20	4370	"	25.2	248	2.25	3.85	46.7	2.15	3.88	44.3
2:30		"	25.2	250	2.08	3.85	43.2	2.01	3.88	41.5
2:40		"	25.3	252	2.13	3.85	44.2	2.01	3.88	41.5
2:50	7247	"	25.3	252	2.30	3.85	47.8	2.20	3.88	45.4
3:00		"	25.2	252	2.18	3.85	45.3	2.17	3.91	44.4
3:10		"	25.0	248	2.16	3.85	41.9	2.14	3.88	42.0
3:20	10022	"	25.1	248	2.14	3.85	44.5	2.01	3.89	41.5
3:30		"	25.3	252	2.25	3.85	46.7	2.17	3.92	44.3
3:40		"	25.1	253	2.27	3.85	47.2	2.16	3.88	44.5
3:50	12998	"	25.2	252	2.22	3.88	45.8	2.08	3.88	42.9
Ave.		80	25.2	251.3			45.17			43.2

Barometer 29.86" Hg

Degree of Vacuum in Jackets	26.4"
Condensed Steam	2112.0#
Average R.P.M.	95.8
Average M.E.P. (H.E.) 45.17	(C.E.) 43.2
Indicated Horse Power	31.96
Brake Horse Power	28.65
Mechanical Efficiency	89.7 %
Steam per I.H.P. per hr. (Dry)	32.6#

T. E. Gretry

F. C. Wernick

Run No. 15.

Vacuum Jacketing — May 5th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
3:50	2998	80	25.2	252	2.11	3.85	43.8	2.13	3.89	43.8
4:00		80	25.3	252	2.22	3.84	46.2	2.09	3.88	43.0
4:10		75	25.4	246	2.13	3.85	44.2	2.09	3.88	43.0
4:20	5869	73	25.5	242	2.24	3.84	46.6	2.14	3.88	44.1
4:30		80	25.1	246	2.22	3.84	46.2	2.18	3.88	42.9
4:40		80	25.2	246	2.14	3.84	44.5	2.00	3.89	41.1
4:50	8742	80	25.1	252	2.21	3.84	46.0	2.12	3.89	43.6
5:00		80	25.1	252	2.42	3.87	48.0	2.26	3.89	46.5
5:10		80	25.4	256	2.13	3.84	44.4	2.03	3.88	41.8
5:20	11616	80	25.5	256	2.30	3.84	47.9	2.20	3.88	45.4
5:30		80	25.2	248	2.21	3.84	46.0	2.09	3.88	43.0
5:40		80	25.3	250	2.20	3.84	45.8	2.08	3.88	42.8
5:50	14486	80	25.4	256	2.18	3.85	45.3	2.05	3.88	42.3
Ave.		79.3	25.3	250.3			45.76			43.33

Barometer 29.86" Hg.

Degree of Vacuum in Jackets		27.05"
Condensed Steam		2102.5#
Average R.P.M.		95.7
Average M.E.P.	(H.E.) 45.76	(C.E.) 43.33
Indicated Horse Power		32.16
Brake Horse Power		28.61
Mechanical Efficiency		89.0 %
Steam per I.H.P. per hr. (Dry)		32.2#

P. E. Gentry

H. E. Wessiek

Run No. 16.

Vacuum Jacketing — May 5th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
5:50	4486	80	25.4	256	2.27	3.85	47.1	2.17	3.88	44.2
6:00		"	25.4	252	2.07	3.85	43.0	1.96	3.88	40.4
6:10		"	25.4	248	1.95	3.84	40.6	1.93	3.88	39.8
6:20	7369	"	25.2	252	2.02	3.85	42.0	1.97	3.88	40.6
6:30		"	25.6	250	2.13	3.85	44.2	2.06	3.88	42.5
6:40		"	25.5	251	2.11	3.85	43.8	2.01	3.88	41.5
6:50	10234	"	25.2	252	2.17	3.85	45.1	2.04	3.88	42.0
7:00		"	25.5	250	2.14	3.84	44.5	2.10	3.88	43.3
7:10		"	25.4	252	2.15	3.84	44.8	2.02	3.88	41.6
7:20	13114	"	25.5	250	2.15	3.84	44.8	2.01	3.88	41.5
7:30		"	25.5	246	2.06	3.84	42.9	1.92	3.89	39.5
7:40		"	25.5	248	2.21	3.83	46.2	2.06	3.87	42.6
7:50	15980	"	25.6	248	2.17	3.86	45.0	2.00	3.84	41.6
Ave.		80	25.45	250			44.15			41.62

Barometer 29.86" Hg.

Degree of Vacuum in Jackets		27.1"
Condensed Steam		2070.0#
Average R.P.M.		95.8
Average M.E.P.	(H.E.) 44.15	(C.E.) 41.62
Indicated Horse Power		31.02
Brake Horse Power		28.65
Mechanical Efficiency		92.3 %
Steam per I.H.P. per hr. (Dry)		32.9#

P. E. Gentry

H. E. Wernicke

Run No. 17.

Vacuum Jacketing — May 5th 1910.

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards			C.E. Cards		
					Area	Length	M.E.P.	Area	Length	M.E.P.
7:50	5980	80	25.6	248	2.16	3.84	45.0	2.11	3.88	43.5
8:00		"	25.6	246	2.11	3.84	44.0	1.97	3.88	40.6
8:10		"	25.6	246	2.14	3.84	44.6	2.01	3.88	41.5
8:20	8875	"	25.6	248	2.15	3.85	44.6	2.02	3.88	41.6
8:30		"	25.6	251	2.23	3.84	46.5	2.08	3.87	43.0
8:40		"	25.6	250	2.12	3.85	44.0	2.00	3.87	41.4
8:50	11746	"	25.0	251	2.13	3.84	44.4	2.02	3.88	41.6
9:00		"	25.2	252	2.16	3.84	45.0	2.12	3.88	43.7
9:10		"	25.2	252	2.14	3.84	44.6	2.07	3.88	42.7
9:20	14629	"	25.2	251	2.11	3.84	44.0	2.02	3.89	41.5
9:30		"	25.2	242	2.09	3.84	43.6	2.05	3.88	42.3
9:40		"	25.4	250	2.19	3.84	45.6	2.06	3.88	42.5
9:50	17499	"	25.3	249	2.18	3.84	45.4	2.03	3.88	41.8
Ave.		80	25.4	249			44.7			42.14

Barometer 29.86" Hg.

Degree of Vacuum in Jackets		27.0"
Condensed Steam		2064.0#
Average R.P.M.		96.0
Average M.E.P.	(H.E.) 44.7	(C.E.) 42.14
Indicated Horse Power		31.47
Brake Horse Power		28.70
Mechanical Efficiency		91.2 %
Steam per I.H.P. per hr. (Dry)		32.25#

G. E. Gritz

H. E. [illegible]

Run No. 18.

Steam Jacketing — May 7th 1910

Time	Rev. Counter	Steam Pres.	Back Pres.	Cal. Temp.	H.E. Cards Area	H.E. Cards Length	H.E. Cards M.E.P.	C.E. Cards Area	C.E. Cards Length	C.E. Cards M.E.P.
9:50	6823	80	24.6	256	2.18	3.83	45.5	2.07	3.88	42.7
10:00		"	24.7	250	2.17	3.84	45.2	2.04	3.88	42.1
10:10		"	24.6	246	2.08	3.84	43.4	1.97	3.88	40.6
10:20	9718	"	24.7	252	2.05	3.84	42.9	1.96	3.88	40.4
10:30		"	24.7	249	2.11	3.84	44.1	2.00	3.88	41.3
10:40		"	24.7	250	2.14	3.84	44.6	2.11	3.93	43.0
10:50	12604	"	24.6	248	2.13	3.84	44.4	1.98	3.88	40.8
11:00		"	24.7	248	2.05	3.84	42.9	1.96	3.88	40.4
11:10		"	24.6	250	2.20	3.84	45.8	2.00	3.88	41.3
11:20	15490	"	24.7	248	2.18	3.84	45.5	2.15	3.88	44.3
Ave.		80	24.65	250			44.43			41.69

Barometer 29.4" Hg

Jacket Steam	39.45# Cond. Steam	1382.0#
Total Steam		1421.45#
Average R.P.M.		96.3
Average M.E.P.	(H.E) 44.43	(C.E) 41.69
Indicated Horse Power		31.3
Brake Horse Power		28.8
Mechanical Efficiency		92.0 %
Steam per I.H.P. per hr. (Dry)		29.92#

A. E. Gretry

F. E. Wernick

SUMMARY

No. of Run	Date of Run	Duration of Run	Kind of Jacketing	A. Pressures Qualities				R.P.M.	Head End		Crank End		Total I.H.P.	B.H.P.	Mech. Eff.	Thermal Eff.	Rankine Eff.	Eff. Ratio	Water Rate Perfect Eng.	Dry Steam I.H.P. hr.
				Steam Pipe	Back	Initial	Final		M.E.P.	I.H.P.	M.E.P.	I.H.P.								
1	4/15/10	120	None	95.80	2.60	98.40	81.40	96.4	43.50	16.15	42.10	14.95	31.10	28.80	92.6	6.58	22.0	29.9	10.80	35.70
2	4/21/10	60	"	90.90	2.54	98.80	82.40	95.6	44.44	16.35	41.94	14.80	31.15	28.60	91.8	6.60	21.75	30.3	10.90	35.60
3	4/25/10	120	"	94.70	2.30	98.00	81.56	95.8	44.26	16.38	43.06	15.24	31.62	28.65	90.6	6.66	22.25	29.9	10.72	35.10
4	"	60	Vacuum	95.80	2.35	98.10	81.37	96.0	44.30	16.34	42.50	15.00	31.34	28.70	91.6	6.64	22.48	29.55	10.60	35.23
5	4/27/10	120	"	95.95	2.17	98.10	81.12	96.0	44.64	16.80	41.48	14.65	31.45	28.70	91.2	6.90	22.75	30.35	10.45	33.75
6	"	90	"	95.95	2.11	97.70	80.70	95.6	44.69	16.48	40.95	14.30	30.78	28.60	92.9	6.85	22.9	29.9	10.4	33.9
7	4/29/10	120	Steam	95.65	2.22	97.70	80.83	96.3	44.20	16.40	42.33	15.00	31.40	28.80	91.7	6.92	23.7	29.2	10.07	33.65
8	"	120	"	95.65	2.30	97.70	80.93	96.1	42.44	15.72	41.27	14.63	30.35	28.75	94.6	7.13	24.55	29.0	9.72	32.7
9	"	120	"	95.65	2.15	97.70	80.74	96.3	42.94	15.94	41.10	14.60	30.54	28.80	94.2	7.44	24.45	30.45	9.76	31.3
10	5/4/10	120	"	96.10	2.21	97.70	80.80	96.1	44.70	16.54	43.42	15.38	31.92	28.75	90.1	7.78	24.8	31.3	9.62	30.0
11	"	60	"	96.10	2.21	98.00	81.00	95.8	44.90	16.58	44.30	15.60	32.18	28.65	89.1	8.05	24.95	32.25	9.54	28.9
12	"	120	"	96.10	2.23	98.00	81.02	96.1	43.60	16.18	41.75	14.80	30.98	28.75	92.7	7.54	24.8	30.8	9.60	30.95
13	5/5/10	120	Vacuum	96.06	2.28	98.45	81.39	95.75	45.04	16.61	43.10	15.20	31.81	28.60	90.0	7.02	22.65	30.95	10.45	33.25
14	"	120	"	96.06	2.28	98.60	81.46	95.8	45.17	16.68	43.20	15.28	31.96	28.65	89.7	7.17	22.7	31.6	10.44	32.6
15	"	120	"	96.06	2.23	98.50	81.35	95.7	45.76	16.89	43.33	15.27	32.16	28.61	89.0	7.25	22.75	31.8	10.4	32.2
16	"	120	"	96.06	2.15	98.50	81.25	95.8	44.15	16.30	41.62	14.72	31.02	28.65	92.3	7.09	22.9	31.0	10.32	32.9
17	"	120	"	96.06	2.18	98.47	81.27	96.0	44.70	16.55	42.14	14.92	31.47	28.70	91.2	7.23	22.85	31.6	10.35	32.25
18	5/7-10	90	Steam	95.85	2.35	98.60	81.57	96.3	44.43	16.50	41.69	14.80	31.30	28.80	92.0	7.85	24.5	32.0	9.68	24.[illegible]

Average Steam Consumption for:

No Jacketing	35.47*
Vacuum Jacketing	33.25*
Steam Jacketing	31.13*

Sample Calculations.

The following is a sample of the complete calculations for one run.

Gauge Pres. (cor.)	= 81.5 #/sq. in.
Barometer	= 29.12 " Hg.
	= 14.3 #/sq. in.
Abs. steam Pres.	= 95.8 #/sq. in.
Back pressure	= 23.7 " Hg.
	= 2.6 #/sq.in.

The initial quality of the steam as determined from the average temperature of the calorimeter for the run from the equation:

$$x_i r_i + q_i = r_a + C(t_c - t_a) + q_a$$

or

$$x_i = \frac{r_a + C(t_c - t_a) + q_a - q_i}{r_i}$$

$$= \frac{970.6 + .6(245.4 - 210.6) + 178.8 - 295.2}{990}$$

$$= 98.4\ \%$$

where x_i is the quality desired, r_i is the latent heat at the initial pressure, q_i is the heat of the liquid at the initial pressure,

r_a is the latent heat at atmospheric pressure, q_a is the heat of the liquid at atmospheric pressure, C is the specific heat of superheated steam, t_c is the average calorimeter temperature corrected, and t_a is the boiling temperature at atmospheric pressure.

The final quality of the steam as determined from the equation:

$$\frac{x_i r_i}{T_i} + \phi_i = \frac{x_f r_f}{T_f} + \phi_f$$

where x_i is the initial quality as before, r_i/T_i is the enthropy of vaporization at the initial pressure, ϕ_i is the enthropy of the liquid at the same pressure, x_f is the quality desired, r_f/T_f is the enthropy of vaporization at back pressure, and ϕ_f is the enthropy of the liquid at back pressure. Solving we get:

$$x_f = x_i \frac{r_i/T_i + \phi_i - \phi_f}{r_f/T_f}$$

which by substituting the value of x_i as already calculated and the others from our tables:

$$= 98.4 \frac{1.1355+.4707-.19078}{1.7786}$$

$$= 81.9\ \%$$

The average revolutions per minute equals the difference in readings of the continuous counter at the beginning and the end of run divided by the length of the run.

$$\text{R.P.M.} = \frac{12045 - 474}{120}$$

$$= 11571/120 = 96.4$$

The average mean effective pressure on head end cards is the average of the mean effective pressures of all head end cards for the run, and for this run was:

$$\text{M.E.P.} = 43.5\ \#/\ \text{sq. in.}$$

The average indicated horse power of the head end was calculated from the mean effective pressure and revolutions per minute given above, the length of the stroke (two feet), and the area of the head end side of the piston

which was 63.6 square inches.

$$H.P. = \frac{43.5 \times 2 \times 63.6 \times 96.4}{33,000}$$

$$= 16.15$$

The average mean effective pressure and indicated horse power were calculated in the same manner for the crank end.

$$M.E.P. = 42.1 \ \#/\text{sq. in.}$$

$$H.P. = \frac{42.1 \times 2 \times 60.8 \times 96.4}{33,000}$$

$$= 14.95$$

$$\text{Total I.H.P.} = 16.15 + 14.95$$

$$= 31.1$$

$$B.H.P. = \frac{6.2832 \times 3.47 \times 96.4 \times 452.5}{33,000}$$

$$= 28.8$$

where 3.47 is the length of the brake arm in feet and 452.5 was the net load on the scales.

The mechanical efficiency as calculated from the above results was:

$$E_m = 28.8/31.1 = 92.6\ \%$$

The thermodynamic efficiency per indicated horse power, as found by dividing the mechanical equivalent of one horse power hour by the heat units supplied per indicated horse power per hour, was:

$$E_t = \frac{2545 \times 31.1}{(.984 \times 890 + 295.1 - 103.4)\ 1229.2}$$

$$= 6.58\ \%$$

where 2545 is the mechanical equivalent of one horse power hour, 31.1 is the total indicated horse power, .984 is the quality of the steam supplied, 890 is the heat of vaporization, and 295.1 is the heat of the liquid at admission pressure, 103.4 is the heat of the liquid at back pressure, and 1229.2 is the total weight of steam supplied to the engine per hour.

In the runs using steam in the jackets, the heat given up by the steam supplied to the jackets was also charged to the cylinder in calculating the above efficiency.

The Rankine efficiency is the theoretical maximum that can be obtained under the given conditions of initial and final pressures as expressed in the formula:

$$E_r = \frac{H_i - H_f}{H_i - q_f}$$

where H_i is the total heat in a pound of steam at the initial pressure, H_f is the total heat in a pound of steam at the back pressure, and q_f is the heat of the liquid at the back pressure. The total heats being:

$$H_i = x_i r_i + q_i$$

$$H_f = x_f r_f + q_f$$

where x_f the final quality is calculated on the assumption of adiabatic expansion, as shown on page 12 in the calculation for the final quality.

Substituting the values of x_i and x_f as already calculated and the remaining values as taken from Peabody's Steam Tables we have:

$$H_i = .984 \times 890 + 295.1$$

$$= 1171.0 \text{ B.T.U.}$$

$$H_f = .819 \times 1016.1 + 103.4$$

$$= 935.6 \text{ B.T.U.}$$

From which we get:

$$E_r = \frac{1171.0 - 935.6}{1171.0 - 103.4}$$

$$= 22.0 \%$$

The efficiency ratio as obtained by dividing the efficiency of the real engine by that of the ideal engine is a measure of the extent to which the theoretical possibilities have been realized and in this case is:

$$E = 6.58/22.0 = 29.9 \%$$

The water rate of a perfect engine is:

$$W_t = \frac{2545}{H_i - H_f}$$

$$= \frac{2545}{1171.0 - 935.6} = 10.8 \#$$

where H_i and H_f are the same as calculated above under Rankine efficiency.

The actual water rate of the engine as obtained by dividing the total weight of dry

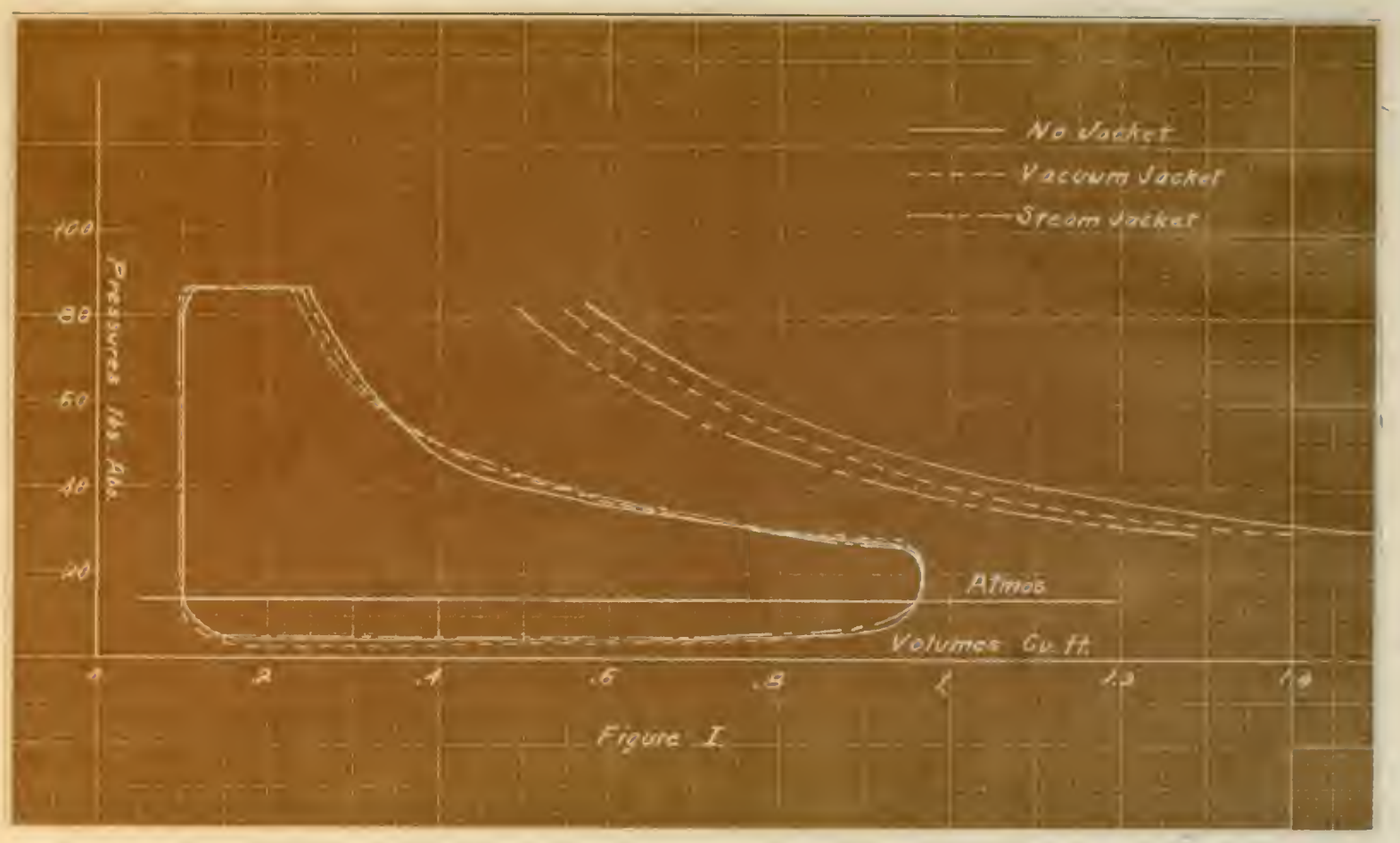

No Jacket
Vacuum Jacket
Steam Jacket
Pressures lbs. Abs.
100
80
60
40
20
Atmos
Volumes Cu. ft.
.2
.4
.6
.8
1
1.2
1.4

Figure I

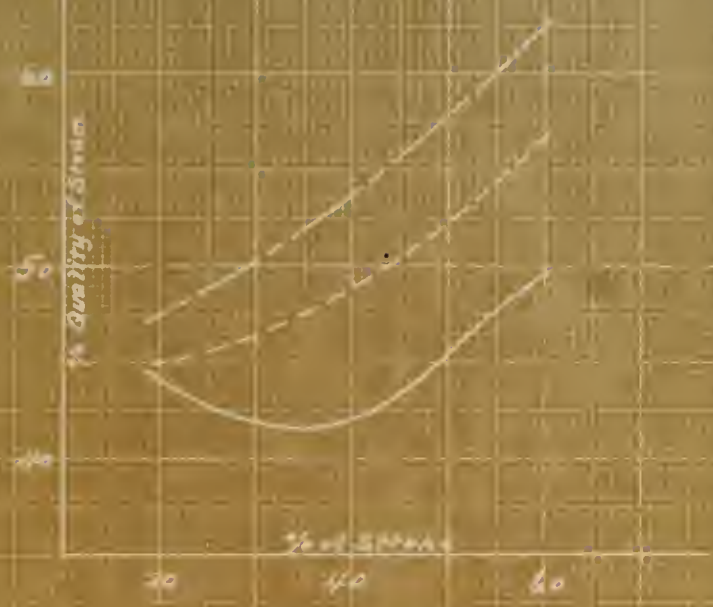


Fig. 2.

% of Stroke	Qualities		
	No Jacket	Vacuum Jacket	Steam Jacket
20	44.2	45.0	47.5
30	42.1	46.3	50.1
40	41.2	49.3	54.7
50	46.0	53.2	57.9
60	49.6	56.4	61.9

steam supplied to the engine per hour by the total average indicated horse power was:

$$W_a = 1229.2/31.3$$
$$= 35.7 \#$$

In the steam jacketed runs the weight of dry steam supplied to the jackets was added to that supplied to the cylinder in calculating the water rate. For those runs using vacuum jacketing no steam was charged to the cylinder for the operation of the air pump since the jackets might have been just as easily directly connected to the condenser and no additional steam required.

The low thermodynamic efficiency and the accompanying high steam consumption were principally due to the small bore of the cylinder as compared with the stroke of the engine. The gain shown for either method of jacketing on this unusually proportioned cylinder would probably not agree with those obtained from one of more practical dimentions.

Our failure to obtain more consistent results was apparently due to the difficulty of maintaining a constant steam pressure at the throttle and a constant load on the brake. Adjustments of the steam pressure and the brake had to be made so frequently that the cut-off was continually fluctuating and it was impossible to get a good average card. The variation in cards was so great that the average of a two hour run may not have given the true average. It is probable, however, that by taking an average of all of the runs made with any one method of jacketing a close approximation of the true average would be obtained.

Fig. 1. shows the three average sample cards and their respective saturation curves. Fig. 2. shows the quality of the steam in the cylinder during expansion for the three methods of jacketing. We include as a part of this report a sheet of the original data for each run and a summary of the calculated results for the full series of eighteen runs.

By averaging the steam consumption, for all runs having the same method of jacketing, we find that No jacketing gives a steam consumption of 35.47 pounds dry steam per indicated horse power per hour, Vacuum jacketing gives 33.25 pounds, and Steam jacketing 31.13 pounds.

This shows a gain of 4.34 pounds for steam jacketing as compared with 2.22 pounds for vacuum jacketing over no jacketing. The percentage of gain being 12.21 for steam, and 6.26 for vacuum jacketing.

We are indebted to Professor Gebhardt and Professor Libby for valuable suggestions as to the manner of conducting these tests; and to Mr. J. C. Peebles for the use of instruments.

This thesis is respectfully submitted to the President and Faculty of the Armour Institute of Technology.

Fandy E. Gentry.

H. Edward Wernick